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FISH PROTEIN CONCENTRATE: A Review

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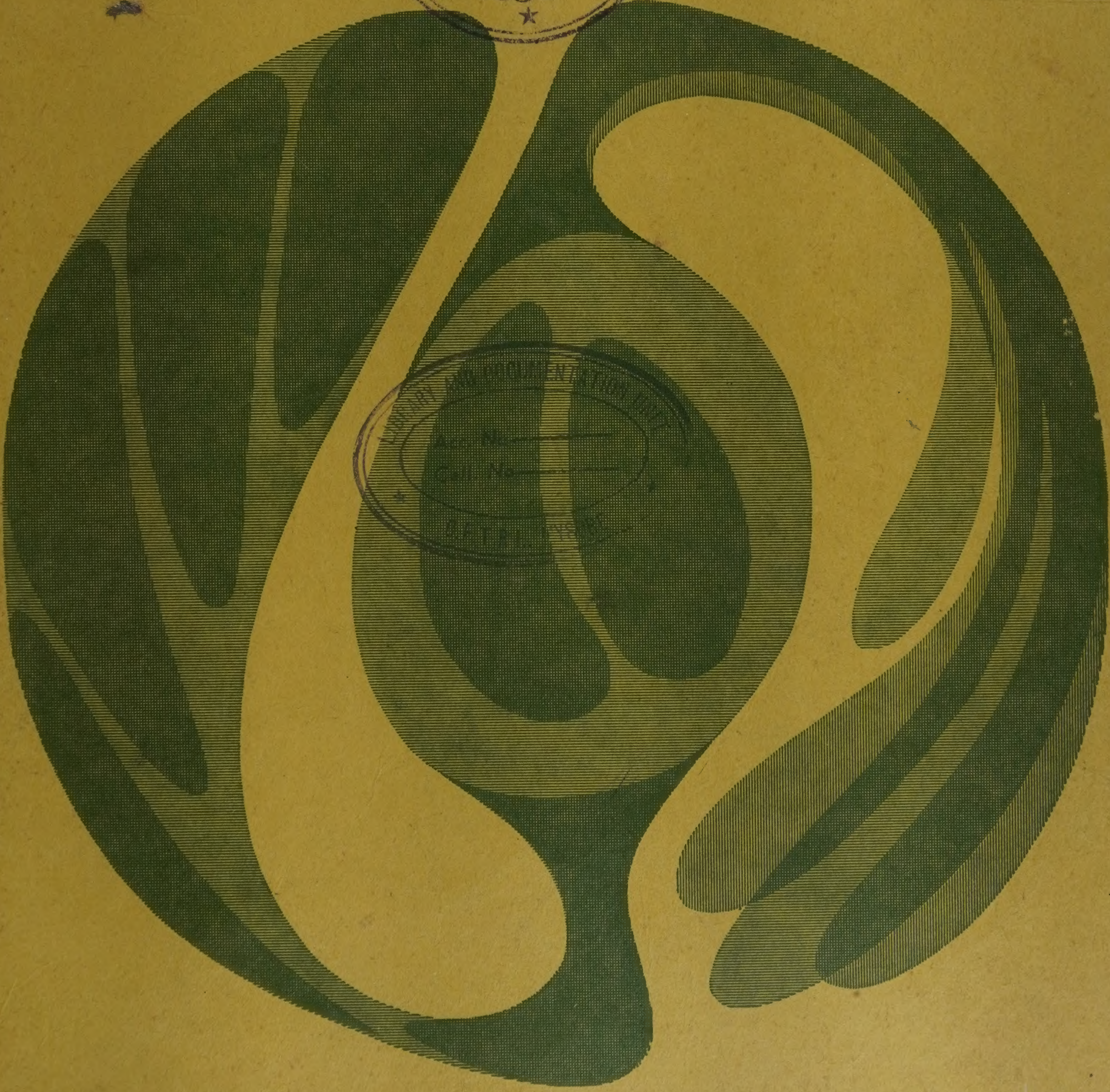

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FISH PROTEIN CONCENTRATE: A Review

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Ministry of Overseas Development

This report was produced by the Tropical Products Institute, a British Government organisation which helps developing countries to derive greater benefit from their renewable resources.

It specialises in post-harvest problems and will be pleased to answer requests for information and advice. Reports such as this one are often written as the result of an enquiry.

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FISH PROTEIN CONCENTRATE (FPC) A REVIEW

Introduction

1 A large proportion of the world catch of fish (about one half in 1967) is processed into fish meal for animal feeding. Most fish meal is produced from oily pelagic clupeoid species of fish which are not normally used for human food and which can be caught on a very large scale in certain world fisheries eg the Peruvian anchoveta and the menhaden of North America. A small proportion of fish meal is, however, made from the more edible gadoid species of fish (cod, haddock, hake etc), the raw material being mainly the by-products of filleting, and surplus fish during temporary market over-supply conditions.

Fish meal is mostly used for pig and poultry feeding in developed countries, and developing countries such as Peru, Chile and Morocco export most of their fish meal output even though the protein status of the national diets is accepted as being too low. It was largely for this reason that there has been so much interest over the past twenty years or so in producing an up-graded fish meal suitable for human consumption, particularly in those countries possessing large marine fishing resources, but which have an inadequate level of protein in their diets. Fish meal type products for human consumption together with traditional fish products such as the fish sauces and pastes produced by fermentation methods in the Far East, are now given the generic term of 'Fish Protein Concentrates (FPC)'. FPC has been defined as including 'Any stable preparation from fish, intended for human consumption in which the protein is more concentrated than in the original fish' (Lovern, 1966). However, the subject matter of this review will be largely restricted to a consideration of flour-like FPV produced by modern processing methods.

History of FPC Production

The production of FPC is by no means new, and there are references to a material called 'Liquamen' prepared by the Romans from salted small fish (Pariser, 1967), as well as the traditional fish sauces of the Far East already mentioned above. The first recorded attempt in more recent years to use fish meal-like material for human consumption was made by the Norwegian Department of Agriculture in 1876, which prepared biscuits made with 'Fish Flour'. However, the first significant attempt to produce an FPC by modern methods was made in South Africa in 1937, when investigations were started into the production of a bland edible fish flour by extraction of dry fish meal with ethanol. Commercial production of FPC started in 1956 using fish meal prepared from Maasbanker and Pilchards as the raw material, and by the end of 1958 more than 1,000 tons of FPC had been produced, mainly for enrichment of brown bread at a rate of 2%. More recently it has been incorporated in the South African infant food 'Pronutro', which was launched on to the market in 1962.

The earliest work in the USA on FPC production was carried out by the Viobin Corporation of Monticello, Illinois, which developed a method in which raw fish was successively extracted with ethylene dichloride and methanol or iso-propanol (Levin, 1959). Since then several other processes for FPC production from fresh fish have been developed by commercial organisations (Knobl, 1967). Work in the USA received a considerable fillip with the initiation of the programme of the Bureau of Commercial Fisheries (BCF) in 1963 and its later extension to the developing countries by the Agency for International Development (AID). Details of the programme of the Bureau of Commercial Fisheries are given elsewhere (BCF, 1966, Snyder, 1967 and Finch, 1969) while those of the AID programme are given by Cordaro (1970). The process selected for FPC production was that of extraction of fresh whole fish with iso-propanol. Considerable difficulty was experienced in obtaining the approval of the Foods and Drugs Administration (FDA) for FPC production from whole fish, and although approval was finally granted in 1967 the raw material source was restricted to fresh red hake (FDA, 1967). Efforts are now being made to produce an FPC acceptable to the FDA from fatty fish such as menhaden, anchovies and herring. The AID Programme has consisted mainly of studies to determine the feasibility of establishing FPC plants in developing and less developed countries, using the technical backing of the BCF. Three countries selected so far, are South Korea, Chile and Morocco, and feasibility studies have been or will shortly be completed. The AID also contracted to purchase 1,000 tons of FPC from a US firm for use in feeding trials in developing countries. Unfortunately the firm in question was unable to supply more than a very small proportion of the amount specified, and the contract has been terminated (Cordaro, 1970).

The process for the production of FPC from fresh fish by extraction with iso-propanol was developed at the Halifax Laboratory of the Fisheries Research Board of Canada, where investigations into FPC were started in 1955. More recently, work in Canada has been mainly directed towards developing suitable processes for producing an FPC acceptable to the Canadian Foods and Drugs Administration using whole herring, whole capelin or cod and haddock trimmings as raw material (Idler, 1969). A large commercial plant with a planned output capacity of 30 tons of FPC per day is being constructed at Canso, Nova Scotia with Canadian Government support, and is expected to start production in mid 1970. Much work has been carried out over the past 10 years or so by Astra Nutrition A.B. of Sweden. A process has now been developed based on iso-propanol extraction of eviscerated deboned fresh fish, which it is hoped to use on a sea-going factory ship (Hallgren and Sjoberg, Osterman, both undated). Work has also been carried out in Norway and Russia aimed at developing processes for the preparation of FPC from fresh fish, whilst attempts have been made to produce an FPC solvent extraction of fish meal in Iceland (Bakken, 1961, Hanneson, 1961, and Knobl, 1967).

Much of the interest in FPC in more recent years was stimulated by the pioneering work in the 1950's of the three UN Agencies directly concerned with improving world nutrition, WHO, FAO, and UNICEF, in their search for new protein foods from unconventional raw material sources (FAO, 1958).

Obviously the UN Agencies were most concerned with stimulating the use of FPC in those developing countries where the population had protein deficient diets, and to this end in 1956 UNICEF financed the construction of a pilot FPC plant at Quintero in Chile. The raw material source for this plant was fresh hake and a dual solvent extraction process of hexane followed by ethanol was used (Allen, 1963, Yanuz *et al*, 1967). The erection of an FPC plant in Agadir, Morocco was supported by FAO in the early 1960s. The raw material used was sardine and the process employed that of extraction of fish meal produced by conventional methods with a solvent mixture including hexane, ethyl acetate and iso-propanol (Knobl 1968, Blake 1969). Neither of these UN Agency sponsored plants has been a success, but efforts are now in progress on the part of the UN Agencies and the Agency for International Development to revive them.

FPC has been produced without UN Agency support in at least three other developing countries. In Peru a process was patented by one of the local fish meal manufacturers, for the production of FPC from white fish meal by extraction with hexane vapour. The product of this process was approved as fit for human consumption by the Peruvian Ministry of Health in 1964 (Harrison, 1964). Work on FPC and fish meal suitable for human consumption has also been carried out by the Central Food Technological Research Institute, Mysore, India (Moorjani and Lahiry, 1970, and Sen *et al*, 1969), in Ghana (Aylward, 1961) and in Uganda (Roels, 1969).

Raw materials and potential world output of FPC

The world catch of marine fish in 1968 has been estimated at around 49.7 million tons of which around 50% was converted into fish meal for animal feeding. World fish meal production in 1968 was estimated at nearly 5 million tons (FAO 1969). Most fish meal is produced from oily pelagic clupeoid species of fish, such as anchovies, sardines and herrings and most of the world catch of some 20.5 million tons (in 1968) of these species is converted into fish meal. The remainder of world fish meal production is mainly from filletings, waste portions and local surpluses of the gadoid fishes (cod, haddock, hake etc). This type of fish meal is normally called 'white fish meal'.

The application of modern fishing techniques is the main factor responsible for the continued increase in world fish landings. It has been estimated that the annual world catch, using existing catching techniques, could expand to a maximum of 100-200 million tons (Snyder, 1966). Consequently the potential world output of FPC could be as high as 18-36 million tons per annum. However, it must be remembered that relatively few fisheries are suited to the production of FPC. A large and regular supply of raw material is essential and the scale of operation must be considerable to minimise costs. The greatest demand upon the predicted increase in fish landings will be for animal grade fish meal and fresh and frozen fish. The market for animal grade fish meal is expanding rapidly largely due to its use in formulated feed mixtures and the projected demand for 1985 amounts to 8.5 million tons (FAO, 1969). Also as fish preservation facilities improve, the demand for fresh and frozen fish will expand considerably. Consequently FPC for human consumption will have to compete for the available raw material. A detailed analysis of the possibilities of expanding supplies of fish for fish meal and FPC is given elsewhere (FAO, 1969b).

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Methods of producing FPC

The commonest procedure for the production if fish meal for animal feed is briefly as follows:-

1. Cooking the raw fish or fish offal
2. Pressing the cooked material to remove some of the water and oil present
3. Drying the press cake
4. Grinding the dried cake so as to produce a fine meal.

There are a number of problems associated with the use of fish meal produced by the above processes as human food. These are briefly as follows:-

1. The possibility of a reduction in the nutritive value of the protein during the cooking and drying stages.
2. The presence of quantities of unsaturated lipids, which are rapidly oxidised by air to produce off-flavours and nutritionally undesirable oxidised fats.

3. The presence of water soluble fishy flavours whihc may be undesirable if the FPC is to be used to fortify bread, flour or other farinaceous staples. These flavours may be caused by phospholipid degradation as well as being present in the fresh fish.

4. Possibly insufficient standards of hygiene, which would make it microbiologically and aesthetically unsuitable for human consumption.

There are two basic approaches to the production of edible FPC:-

1. The upgrading of animal feed fish meal

2. The use of special processes to prepare FPC directly from raw fish.

Both of these approaches are based on extraction with various solvents to remove the lipids and as far as considered necessary the water soluble fish flavouring constituents. Three basic types of FPC have been defined by FAO (Winsor, 1969):-

1. Type A: an almost bland powder with a total fat content not exceeding 0.75%

2. Type B: a powder with no specifications as to taste or odour with a definite fishy flavour and a total fat content not exceeding 3%

3. Type C: a normal fish meal produced under satisfactory hygienic conditions.

One of the main problems associated with Type A when it is used for purposes where it is essential for it to be bland, is that of flavour reversion due to the small amount of fat present. For this reason it is desirable that Type A FPC should be produced with a maximum total fat content of 0.1-0.2% (Hallgren, 1968). The exact type of process used depends on the type of FPC to be produced, particularly with regard to the degree and manner of solvent extraction. The earliest FPC processes used feed grade fish meal as raw material. Examples of this have already been given and include those developed in South Africa (Dreosti and van de Merwe, 1962), Iceland (Hanneson, 1961), Peru (Harrison, 1964), Chile (Yanuz *et al,* 1967), and Morocco (Knobl, 1967). These processes were all based on the extraction of the dry meal with solvents. In the South African process the meal was extracted with ethanol which removed the fishy flavour as well as the lipids giving a Type A FPC containing 80% protein and 0.5% fat. The Icelandic and Peruvian processes both involved hexane extractions which in the latter case produced a Type B FPC containing 1% fat and 71% protein. The process used at the Chilean plant (at Quintero), involves the dehydration of comminuted fresh hake by drying at 70-100^{o}C, and subsequent extraction with 95% ethanol. The Moroccan (Sonafap) process involved the extraction of the conventionally prepared fish meal with a solvent mixture of hexane, ethyl acetate, and iso-propanol which simultaneously defatted and deodorised the meal to produce a Type A FPC.

There is no reason why Type B FPC should not be produced from hygienically prepared fish meal, provided that care is taken to use solvents which do not leave toxic residues, but for the production of bland Type A FPC it is now considered necessary to use special processes developed for the conversion of fresh raw fish directly into FPC. This is because the inevitable delay between the production of the meal and its further processing and the inevitable partial oxidation of the lipids during drying makes it more difficult to defat and deodorise satisfactorily by solvent extraction. There is, however, no reason why press cakes prepared from freshly caught fish should not be processed into Type A FPC, and in fact this procedure was used in the original 'Astra' process developed in Sweden in which conventionally prepared press cake is extracted with iso-propanol (Hallgren, 1968). Type C FPC is simply an hygienically prepared fish meal and no solvent extraction is required. Lipid oxidation may be avoided to some extent by addition of antioxidants to the press cake before drying.

There are two basic requirements for processes to produce FPC from raw fish by solvent extraction, namely to dehydrate and to defat at temperatures low enough to avoid any possibility of reduction in protein nutritive value. The first process which

satisfied these requirements was the so-called 'Viobin' process developed in the USA (Levin, 1959). This process involves the following stages (Swendsen, 1967):-

1. Fresh raw fish is comminuted in a grinder.

2. The comminuted fish is extracted at 71°C in an agitated tank with ethylene dichloride (EDC).

3. The oil is extracted by the EDC while the tissue water distils off as an azeotropic mixture with a portion of the EDC.

4. As water and oil are removed the density of the fish tissue increases until it falls to the bottom of the extraction vessel.

5. The wet proteinaceous solids are dried under vacuum.

6. The dry solids are ground into a meal.

7. Normal precautions are taken to recover all the solvent used.

The dry material resulting from this process is normally a Type B FPC containing about 70% crude protein. The protein content may, however, be increased by partial separation of bones before extraction with EDC. The fishy odour is retained but this may be removed by a final extraction with iso-propanol to form a bland Type A FPC. The Viobin process with a final extraction stage with iso-propanol was adopted by Alpine Marine Protein Industry Inc when they contracted to manufacture 1,000 tons of FPC for the AID using a new plant erected at New Bedford, Massachusetts (Cordoro, 1970).

The best methods of Type A FPC production from raw fish developed so far are those based on extraction with ethanol or iso-propanol. These solvents have the advantage of being able simultaneously to extract fat, water and undesirable flavours and odours. Iso-propanol is normally preferred to ethanol because of the high excise duties on ethanol in most countries. The first process using iso-propanol as the only extraction solvent was the so-called 'Halifax' process developed at the Technological Research Laboratory of the Fisheries Research Board of Canada, Halifax. This involves the following five stages (Idler, 1969):-

1. Fresh skinned cod fillets (or other material) are ground to a size of one quarter of an inch, and mixed with sufficient iso-pronanol (99%) to give a 70 : 30 iso-propanol - water ratio in the total mixture. Sufficient polyphosphoric acid is added to reduce the pH to 5.5. The partially dehydrated and denatured fish is then further comminuted to a size of 1/8 inch or less.

2. The material is heated under reflux at 82°C for about 30 minutes after which most of the liquid is removed by centrifugation, and the cake remaining comminuted to ½ inch size pieces.

3. The shredded cake is extracted as before but with 70% aqueous iso-propanol and again comminuted to ½ inch pieces.

4. A final extraction is made with iso-propanol (99%) as in stages 2 and 3, to produce a cake with a fat content of less than 0.06%.

5. The cake is dried at 38-43°C to a moisture content of 3-4%.

FPC from cod fillets has a crude protein content of around 93%. Type A FPC has been prepared from whole cod, herring and cod trimmings using this process, but as would be expected protein content is rather lower than that from cod fillets. Iso-propanol is also used as the only solvent in the process developed by the US Bureau of Commercial Fisheries for large scale FPC production from red hake (Bureau of Commercial Fisheries, 1966). This process is very similar to the Canadian process described above and involves the three stage extraction of the comminuted material with aqueous iso-propanol at temperatures of around 75°C, to produce a Type A FPC containing less than 0.5% total lipids. The final extracted cake is dried in a

rotating vacuum dryer and ground to a fine powder. The 'Astra' process, which also involves the extraction of comminuted fresh fish with iso-propanol, has already been mentioned.

Physical properties, flavour and acceptability

Type C FPC may be regarded as being a hygienically prepared fish-meal. It has a strong fishy flavour and contains varying amounts of rancid fat, depending on the nature of the raw material and its handling prior to processing. Although it would be quite unacceptable to people used to Western European diets, and would be difficult to blend with staples such as bread, it is acceptable as a food in its own right in large areas of the world. Such areas include the Far East and parts of Africa and South America. For example both fish meal and biscuits containing 12-14% fish meal were found to be quite acceptable to school children in West Malaysia (Thomson and Merry, 1962), while locally prepared fish meal has been found to be quite acceptable to sections of the population in Peru (Lovern, 1966) and Ghana (Aylward, 1961).

Freshly prepared Type A FPC has been described as a bland white powder with a gritty texture due to the presence of skin and bones in the raw material. This grittiness may be removed to a large extent by removal of bones during processing or grinding the FPC very finely. Type A FPC is completely unattractive as a food in its own right and must be consumed as an additive to other acceptable foods. As has been previously mentioned it is very liable to suffer from the problem of flavour reversion after preparation unless the lipid content is reduced to levels well below the maximum of 0.75% originally specified by FAO. The problem of flavour reversion may be linked to the species of fish used as raw material and FPC prepared from gadoid fishes such as cod may well be more stable than those prepared from species of oily fish (Lovern, 1969). Flavour reversion is, however, a general problem associated with Type A FPC, and one leading authority on fish processing recently remarked that he had never yet encountered a Type A material which had not suffered flavour reversion during storage (Lovern, 1969). The possibility of flavour reversion is obviously a serious disadvantage if it is desired to fortify staple farinaceous products such as bread where a fishy flavour would be highly undesirable.

In addition to the flavour problem mentioned above, the use of Type A FPC as a food additive may also be severely restricted by its lack of functional properties and gritty texture. For example the presence of FPC in bread in quantities exceeding more than a few per cent may have an adverse effect on its physical quality. The lack of functional properties, particularly solubility has been one of the main factors causing the delay in the commercial use of FPC by the American food industry. There are possibilities that functional properties could be improved by further processing eg treatment with alkali to improve solubility (Tannenbaum *et al*, 1970), but this would obviously make the production process much more expensive. The Type A concentrates currently available must, however, be regarded as suitable for addition to conventional cereal based food products, eg bread, pasta, infant foods etc, only in small quantities if a significant deterioration in flavour and physical properties is to be avoided. These aspects will be discussed more fully later. Type B FPC is obviously unsuitable for use as an additive to cereal based products like bread due to its fishy flavour and can only be used in the same way as Type C products. However it has certain nutritional advantages over Type C FPC, and these will be discussed later.

Quality standards and composition

When the FAO defined the three types of FPC referred to above, the following standards were laid down with regard to composition and bacteriological contamination:-

	Type A	Type B	Type C
Moisture, maximum per cent	10.0	10.0	10.0
Protein (N x 6.25) calculated on 10% moisture basis, minimum per cent	67.5	65.0	60.0
Pepsin Digestibility, per cent	92	92	92
Available Lysine, Minimum, per cent of protein	6.5	6.5	6.5
Total lipids, maximum, per cent	0.75	3.0	10.0
Chloride, maximum, per cent	1.5	1.5	2.0
Silica, maximum, per cent	0.5	0.5	0.5

Additional stipulations with regard to Type A FPC were:-

1. It should have no more than a faint odour and taste when wetted with boiling water in a closed container.

2. After storage for a period of six months in a sealed container maintained at a temperature of 26.5°C, there should be no development of off-flavours (flavour reversion) or loss in protein quality as indicated by reduction in available lysine or pepsin digestibility.

3. The product should be free from *Enterococci, Salmonella/Shigella,* Coagulase-positive *Staplylococci* and *Clostridia,* having a total bacterial plate count at 37°C of not more than 10,000 per gram.

It was also stated that Type A should be completely free from harmful solvent residues, and that safety tests with animals should be carried out. Additives or preservatives were not permitted in Type A but could be added to Types B or C if permitted by the legislation of the consuming country.

Further requirements for FPC Types B and C were limited to a stipulation that protein quality as indicated by available lysine and pepsin digestibility should not decrease during hermetic storage for a period of six months at 26.5°C, and that the same bacteriological requirements as for Type A should apply for *Enterococci, Salmonella/Shigella,* Coagulase-positive *Staphylococci,* and pathogenic anaerobes. These specifications were never satisfactory for Type A because the maximum lipid content of 0.75% was too high to avoid the development of off-flavours during storage. New draft provisional guidelines and specifications for FPC were therefore drawn up by FAO, which identified only two types of FPC prepared from raw fish:-

Type A:- a dry, defatted, tasteless and odourless product, white to light yellow or light grey in colour

Type B:- a dry, partly defatted and partly deodorised product, yellow or greyish in colour.

In addition it was stipulated that raw material used for FPC production must be fish or parts thereof fit for human consumption, and that it must be processed under approved sanitary conditions.

Specifications were laid down for maximum total lipid contents of 0.5 and 5.0% for A and B respectively while minimum protein content is increased to 75 and 70% respectively for Types A and B. The requirements for maximum silica and chloride were replaced with specifications for maximum total and acid insoluble ash, while a maximum fluorine content of 100 parts per million was laid down. Maxima of 250 and 5 parts per million were laid down for residues of iso-propanol and ethylene

dichloride respectively, the two solvents most commonly used for FPC production. It was also stipulated that the packaging and storage of the final product should adequately protect it from damage due to adverse ambient conditions or rodent and insect pests, and that Type A should be completely stable with regard to flavour and protein nutritive value when suitably packaged and stored for six months at 40°C. A more comprehensive standard for the presence of micro-organisms was laid down, and stipulations were made regarding the use of solvents and additives, and the widest of toxicological assays.

One of the greatest stumbling blocks to the development of commercial FPC production in the USA has been the high standards demanded by the Foods and Drugs Administration (FDA). In 1961 the FDA were petitioned by the Bureau of Commercial Fisheries (BCF) to establish a US standard for FPC, and in 1963 the interim ruling was made that FPC should not contain fish heads or viscera. This would obviously have made FPC production quite uneconomic and after considerable representations the FDA in 1967 gave their approval to FPC prepared from whole hake, provided that it was sold in packs not exceeding one pound (454 g) weight (FDA, 1967). A number of compositional, sanitary and nutritional standards were laid down, many of which were later adopted in the FAO guidelines for Type A FPC. FDA-approved FPC corresponds to a Type A rather than a Type B product with regard to both organoleptic characteristics and oil content. Both a modified Viobin process using successive extraction with ethylene dichloride and iso-propanol and the BCF method developed using iso-propanol alone were approved. A petition has now been presented to the FDA by the BCF for the production of FPC from other species of fish including oily species such as anchovies and herrings (Department of Health, Education and Welfare, 1969).

Specifications for FPC to be supplied to AID under their contract with a US processor (Alpine Marine Products Inc) were based on those of the FDA with certain modifications (PAG, 1969).

The composition of fish meal and FPC obviously varies with the type of processing employed and the raw material source. The crude protein, fat (crude fat or total lipid, as indicated) and ash contents of some examples of fish meal and FPC are given in Table 1. Further details of the composition of FPC produced in the USA (by the BCF), Canada and Chile are given by Sidwell *et al,* 1969, Power, 1962 and Yanez *et al,* 1967 respectively. Lipid contents are well below the maxima, reflecting the importance of removing all but the slightest traces of lipids if flavour reversion is to be avoided.

The amino acid compositions of some examples of FPC protein together with that of other important food proteins are given in Table 2. Both the lysine and methionine content of FPC are high compared with vegetable proteins such as soya and groundnut, which makes it very suitable as a protein supplement to diets based on staple cereals. The sequence of limiting amino acids has been determined for the BCF product (from red hake) and methionine was found to be the first limiting amino acid (Stillings *et al,* 1969).

It is important that processing should be carried out in such a way that the nutritional value of the protein in the product is not adversely affected. The principal danger is loss in availability of lysine which can be minimised by avoiding excessive temperatures during processing. A minimum available lysine content of 6.5 % of crude protein content (N x 6.25) has been suggested by FAO (Winsor, 1969). Care must also be taken that solvents used during processing do not adversely affect the nutritional availability of amino acids. Ethylene dichloride (used in the Viobin process) has been reported to seriously limit the availability of methionine by forming a toxic compound (chloro-choline chloride) which is removed by subsequent iso-propanol extraction (Munro and Morrison, 1967). Cystine is also reported to react with ethylene dichloride to form a biologically non-available compound (Morrison and Munro, 1965).

TABLE 1
COMPOSITION OF SOME FISH MEALS AND FPC
(per cent dry matter)

Product	Source	Protein (N x 6.25)	Crude Fat (Ether Extract)	Fat (Chloroform/ Methanol Extract)	Ash
Menhaden Meal	USA[1]	65	11	?	22
Herring Meal	– [1]	76	11	?	11
Pilchard Meal	South Africa[1]	71	7	?	?
FPC (whole sardines)	Morocco[2] (Agadir)	88.5	?	0.44	13.1
FPC (whole cod)	Canada[3]	84.7	0.02	0.06	15.7
FPC (whole herring)	Canada[3]	89.7	0.1	0.2	7.8
FPC (whole red hake)	USA[4]	87.2	?	0.2	14.5
FPC Type A (Specifications)	FAO[5]	86.5 (Minimum)	?	0.55 (maximum)	16.7 (minimum)

1. Lovern, 1966
2. FAO, 1969
3. Power, 1962
4. Bureau of Commercial Fisheries, 1966
5. Winsor (1969)

TABLE 2
ESSENTIAL AMINO ACIDS OF FPC AND OTHER PROTEIN CONCENTRATES
(per cent of N x 6.25)

Amino Acid	FPC[1] Herring (Sweden)	FPC[1] Hake (USA)	Soya cake[2]	Groundnut Flour[2]	Casein[2]	Whole Hen's Egg[2]
Iso-leucine	4.47	4.56	4.8	3.3	5.5	6.3
Leucine	8.70	7.78	7.8	6.4	10.7	8.8
Lysine	9.14	8.41	6.1	3.5	8.3	7.0
Methionine	2.94	3.30	1.4	1.1	2.9	3.4
Cystine	–	0.77	1.7	1.3	0.4	2.4
Phenyl-alanine	4.48	4.24	5.0	5.0	5.4	5.7
Tyrosine	3.17	3.35	3.8	3.9	5.9	4.2
Threonine	5.24	4.47	4.3	2.6	4.8	5.1
Valine	5.18	5.26	5.2	4.2	6.9	6.9
Tryptophan	1.40	1.03	1.5	1.0	1.6	1.5

1. Weinberg, (1967)
2. FAO, (1968)

However, recent work has indicated that it is possible to prepare a non-toxic FPC by ethylene dichloride extraction alone by adjusting processing conditions (Ershoff and Rucker, 1969). There is no doubt that the major processes developed for FPC production, namely the BCF and modified Viobin processes (USA), the Halifax process (Canada), the Astra process (Sweden), the SONAFAP process (Morocco) and the Quintero process (Chile), can all produce FPC to the FAO specifications. FPC produced to this specification is undoubtedly a wholesome product of high protein status, but cannot be relied upon to remain completely bland after production. Fundamental studies are now in progress in the USA to investigate the nature of the residual lipids and water soluble flavouring materials involved in flavour reversion and these may eventually provide an answer to this problem with Type A FPC (Medwadowski *et al,* 1967 and 1968, Wick *et al,* 1967).

Nutritive Value

The high nutritional value of FPC protein has been confirmed by numerous biological tests. For example FPC prepared by the BCF from a number of raw material sources had protein efficiency ratios slightly greater than a casein control (Sidwell *et al,* 1969). Many feeding trials of FPC to humans have been carried out in recent years with invariably good nutritional response (Stillings, 1967, Chichester and Monckeberg, 1969), and it may now be taken that FPC produced to FAO specifications by the processes mentioned above is an excellent protein food supplement. The exceptionally high lysine content makes it particularly suitable for supplementing diets deficient in lysine eg those based on wheat flour.

In addition to its potential as a protein supplement, FPC contains quantities of calcium and phosphorous and other minerals which may be useful if they are lacking in the diet to be supplemented. A high content of fluorine is considered undesirable (FAO 1969) and a maximum of 100 ppm has been recommended by FAO.

The presence of solvent residues or toxic substances produced during solvent extractions, is a potential hazard which has attracted much attention. Tolerances have been established for ethylene dichloride and iso-propanol, but none has yet been laid down for hexane and others. The liability of chlorinated hydrocarbon solvents to react with protein is well known, and the difficulties experienced with the use of ethylene dichloride have already been mentioned above. The presence of large quantities of readily oxidised lipids in FPC may be a serious nutritional disadvantage even if their flavour is acceptable to the consumer, due to their adverse effect on the fat soluble vitamins in the diet. For this reason the consumption of FPC containing more than 5% total lipids (the new maximum for Type B) is not now recommended. However, as the suggested rate of inclusion of FPC is known diets is only about 20 g of 70% protein material per day, a Type C FPC (ie an edible fish meal) containing 10% lipid would only supply 2 g of oxidised fat per day, which might not be excessive (Lovern, 1969). Edible fish meal cannot, therefore, be completely ruled out for human nutritional purposes. The production of edible fish meal from species of fish rich in natural antioxidants (Aylward; 1961) of the addition of antioxidants during processing could well be methods of avoiding undesirable fat oxidation.

Potential Usage and Presentation

Type B FPC and edible fish meal retain the original fishy flavour and can only be presented to consumers who are willing to accept this. There are large areas of the world where dried fish-flavoured materials are readily accepted, and there is no reason why Type B FPC or edible fish meal should not be sold directly as a food additive eg a soup condiment. Areas of the world where these products would be likely to find ready acceptance include parts of South America, West Africa and the Far East.

Most effort so far has gone into the more difficult proposition of producing the bland, Type A FPC suitable for feeding to populations which are unlikely to accept the fishy flavour of Type B. The problems of presenting Type A FPC are very much greater than for Type B, due to its unattractive appearance, lack of functional properties and gritty texture. Moreover, as has been previously mentioned, Type A FPC is very liable to undergo flavour reversion after manufacture and invariably possesses a faint fishy taste and odour.

The physical properties of Type A FPC make it quite unacceptable as a food in its own right and it can only really be presented as an additive to an established food. Staple items of the diet such as bread and pasta are obvious potential candidates for fortification with FPC, while FPC can be added to special high protein foods such as cereal–based infant foods and even milk shakes.

With regard to fortification of bread and pasta, the major difficulties encountered in addition to possible flavour problems are the adverse effect of FPC on the structure due to its lack of binding properties and low dispersibility. The possibilities of using Type A FPC to increase the protein status of bread, pasta products, biscuits and beverages has been extensively studied as part of the BCF programme of research (Sidwell, 1967, Sidwell *et al,* 1969, Kwee *et al,* 1969). It was found that even 5% of FPC had a noticeable effect on loaf volume and crumb structure while as the percentage was increased to 25% the colour gradually changed from white to light tan. Dough containing FPC required a longer kneading time and increased percentages of water. The nutritive effect of even a 5% addition of FPC on protein status was, however, likely to be fairly marked in that lysine and methionine content were almost doubled. However, while the effect of FPC admixture on the quality of European type bread is likely to be a serious disadvantage, it has been pointed out (FAO, 1969c), that this may not be so for the thin, flat breads of Arab countries and chapatis of India. The addition of FPC to biscuits at levels of up to 15% was said to have no adverse effect on factors affecting their acceptability. Pasta products have also been prepared from wheat, rice, maize, soya and tapioca flours with 10% added FPC, with varying degrees of success.

In addition to the BCF experimental programme mentioned above, which has been mainly designed to produce FPC fortified foods acceptable in Western European type diets, it should be mentioned that FPC has been used for fortification of brown bread and for inclusion in an infant food ('Pronutro') in South Africa. The South African FPC was reported to have no effect on physical properties of brown bread up to an inclusion rate of 4%, and the inclusion rate of 2% used in practice would be expected to be quite safe from this standpoint (Dreosti and van der Merwe, 1962). The rate of inclusion of FPC in Pronutro is not known.

The inclusion of FPC in beverages, powdered soup etc is restricted by its lack of functional properties, and efforts by the BCF to develop completely acceptable products incorporating FPC have not been very suffessful. A laboratory scale process for the solubilisation of FPC by hot alkaline extraction has been developed, and this product may well be more suitable as a beverage ingredient (Tannenbaum *et al,* 1970 a and b). Solubilised FPC has also been suggested as an ingredient of synthetic textured protein products. Doubts have, however, been expressed regarding the possible adverse effect of alkaline treatment on nutritive value, due to racenisation of the protein amino acids.

Economics of Production and Marketing (All costs are given in US currency)

The cost of producing FPC or edible fish meal is, of course, dependent on the cost and availability of raw material and the amount of processing to which it is subjected. The cheapest material currently available is Peruvian fish meal which can be profitably produced at around 14.5 cents per pound of protein ie about 9 cents per pound for material containing 65-70% crude protein. The cost of the raw material is of vital importance when it is considered that 6-7 pounds of wet fish are required to produce one pound of FPC. Also FPC can be produced most economically in large scale plants where the fixed overheads are spread over a high rate of production. For these, a large and regular supply of raw material is essential so that maximum use may be made of the plant. The degree of processing necessary will be dependent on the nature of the raw material and the type of FPC to be produced. Oily fishes such as herring and sardine require more careful processing than white fish such as haddock, if a bland, stable, Type A FPC is desired. Also the degree of fineness of the product which is required is important, as grinding costs can be high. Thus it has been estimated that the cost of grinding FPC from a 30 to a 100 mesh degree of fineness is 1.5 cents per pound (Lovern, 1969). Interest in the use of FPC for human food grew rapidly around 1961 and a figure of 15 cents per pound was widely regarded as the upper price limit for any form of FPC (Lovern, 1969). Prices for fish meal have risen by 3 cents per pound since 1961 but the lowest estimates at present for FPC

production are approximately 25 cents per pound assuming raw material costs of 1 cent per pound (Snyder, 1967). For higher raw material costs and smaller quantities the price could be considerably higher (Lovern, 1969). This increase which is largely due to the cost of extraction reflects the difficulties which have been encountered in producing Type A FPC. The cost of processing fish into Type A FPC has been the subject of a recent detailed study by the Massachusetts Institute of Technology in 1970. Under US conditions it was estimated that a plant with a daily capacity of 200 tons of raw material operating on an equivalent of 260 days full capacity working, would product Type A FPC at a cost of 16 cents per pound exclusive of raw material cost. Any reduction in output would of course greatly increase processing costs. The assumed process involved is that of solvent extraction with iso-propanol. Raw material costs for Atlantic seaboard operations have been estimated at, at least, 3 cent per pound for hake and 1.5 cents per pound for oily fish (herring, mackerel and capelin) which would give total production costs of around 35 and 26 cents per pound respectively. Raw material for Pacific seaboard operations would be likely to be considerably cheaper and total production costs of 20-35 cents per pound have been envisaged for FPC produced from hake or anchovy.

The only commercial FPC plant to operate so far on the Atlantic seaboard (Alpine Marine Products) contracted to produce Type A FPC for sale to the AID at a price of 42 cents per pound, but, as has previously been mentioned was unable to fulfil its contract. A new plant being constructed by Cardinal Proteins Ltd at Canso, Nova Scotia is planned to produce Type A FPC using the Halifax process at an estimated selling price of 35 cents per pound on a 200 ton per day raw material input basis. The operations of this plant are to be linked with a fish filleting plant which will supply part of the raw material for FPC production, and a fish meal plant which will provide an outlet for any excess raw material. Both of these selling prices are compatible with the estimated production cost as calculated by MIT. On the Pacific seaboard the Oceanic Development Corporation is planning to build a plant of similar capacity to that of Cardinal Proteins Ltd, to process anchovy into Type A FPC using the Viobin process. The selling price of the product has been estimated at 25 cents per pound, which again is compatible with the MIT estimated production costs.

MIT have also made an estimate for the cost of producing Type A FPC by iso-propanol extraction in a plant with a capacity of 200 tons of raw material per day, in Chile. Chile is an ideal location for FPC production in that it has ample fish resources, while the national diet is deficient in protein. Taking into regard the 'Shadow', rather than the official foreign exchange rate for Chilean currency, it was estimated that the opportunity cost of producing FPC in Chile in a plant of this capacity operated for 150 days per year, was about 25 cents per pound. This figure is for processing and production alone and ignores promotional and marketing costs. It has already been mentioned that fish meal is available at considerably lower prices than those estimated for Type A FPC (9 cents per pound in Peru) and the additional cost of producing Type A must be attributed to the exhaustive solvent extraction necessary to remove all but the smallest traces of lipids and flavouring materials. Partial extraction of the lipids to form Type B FPC or an edible fish meal would be much cheaper.

As has been already mentioned, Type A FPC is completely unacceptable as a food in its own right and must be used as an additive to fortify established acceptable foods. High protein content has not as yet been established to any extent as a desirable property for selling foods even in the more sophisticated Western European type market, except perhaps in the USA. It should be noted, however, that vitamin content is now well established in the public image of many developed countries as a desirable property of foods, and it is not inconceivable that the impact of advertising may eventually change matters. However, if material is to be added to an established food, its use could under present circumstances only be justified, on purely commercial considerations, if it provided some improvement to the physical properties of the food.

It has already been noted that FPC is particularly lacking in functional properties, and if added in quantities of more than 5% or so, could result in an adverse effect on the physical properties of the food product. Attempts noted above to improve the functional properties of FPC by further processing could make it a more useful food additive, but would inevitably increase its cost. Under these circumstances it is difficult to see how Type A FPC could ever be used on a commercial basis for fortification of foods, and any use for this purpose would have to be by Government intervention eg by legislation for the mandatory fortification of certain foods. Mandatory fortification shcemes could only be justified in developing countries with protein deficient diets and would do nothing to assist FPC marketing in developed countries such as the USA. There might also be an outlet for Type A FPC as an ingredient of infant weaning foods or for low cost institutional feeding but this would depend upon their price compared with other competing materials assessed on a nutritional basis.

Several attempts have been made to assess the relative cost of Type A FPC compared with other protein concentrates such as oil-seed flours and skimmed milk powder. In assessing relative costs it is, of course, essential to take into consideration the protein status of each material and the presence of other substances of potential nutritional value which may be present eg the high calcium and phosphorous content of FPC. The US market prices of some of these materials calculated on a unit reference protein (whole hen's egg) basis are given in Table 3. It will be seen that even at 25 cents per pound FPC is uncompetitive with soya flour and only just equal to skimmed milk powder.

The true value of FPC protein when used for fortifying staple foods must, however, be assessed in terms of its supplementary effect on the protein of the staple food. FPC protein is particularly rich in the two amino acids most commonly found to be limiting in vegetable proteins ie lysine and methionine, and it therefore increases the 'Net Protein Utilization' (NPU) of the protein in the staple cereal or other farinaceous material to which it is added. Increase in NPU of the protein of staples can also be effected by admixture of small quantities of synthetic lysine and methionine or other protein concentrates such as soya or dried milk, and the factors determining the most suitable material for fortification will be the cost of obtaining the desired nutritional objective, the availability of materials, and the effect the additive may have on the physical and organoleptic properties of the staple.

A comprehensive economic evaluation of cereal fortification with synthetic lysine, soya flour, skimmed milk powder and FPC was carried out recently (Kracht, 1969). It was concluded that fortification with FPC was the cheapest method of increasing the protein status of wheat flour by rectification of lysine deficiency, taking into regard the contribution each material could make to bringing the mineral and vitamin status of the flour to the required level. The other materials considered were placed in the following order of increasing cost:- synthetic lysine, soya flour and skimmed milk powder. Unfortunately Kracht took the price of FPC as 19 cents per pound, so in the light of present estimates of the likely cost of Type A FPC, it is unlikely that his conclusions are valid. On the basis of a price of 25 cents per pound, FPC is a more expensive method of fortification of wheat flour than synthetic lysine, the cost ratios taking lysine as unity being lysine 1.0 : soya flour 1.16 : skimmed milk powder 1.41 : FPC 1.14. This calculation would appear to suggest that Type A FPC .produced at a price of 25 cents per pound could under free market conditions compete with soya flour as a material for fortifying wheat based diets, but it would not be competitive with a synthetic lysine and mineral mix. However, Kracht's calculation does not take into account other amino acids such as threonine or methionine which may also be important.

The alternative methods of supplementing the protein deficient Chilean diet to produce a desired daily protein intake has recently been studied (MIT, 1970). It was concluded that Type A FPC produced at a cost of 25 cents per pound was from 25-40% more expensive in terms of the country's resources to achieve the desired result, than the least expensive alternative. It was further suggested that to compete

TABLE 3
Cost and nutritional value of materials for protein fortification of foods

Product	Estimated Cost US cents per pound	Protein per cent	Estimated Cost per pound of protein (US cents)	Net protein utilisation[2]	Estimated Cost per pound of reference protein equivalent
FPC (Cardinal Protein Ltd)	35	80	44	79.5	55
FPC (Oceanic) FPC (Chile)	25	80	31	79.5	39.5
Soya Flour	10.2[1]	50	20.4	61.4	31
Skimmed Milk Powder	11.7[1]	36	32.5	81.6	40

1. Kracht (1969), USA prices
2. FAO (1968). Reference Protein whole hen's egg of NPU 93.5

with other possible protein concentrates suitable for fortifying staple foods, the opportunity cost of production of FPC in developing countries importing protein sources other than fish would have to be less than 20 cents per pound, before it could be considered to offer any substantial economic advantage over imported alternatives. To compete on the world market FPC would have to be produced at an opportunity cost of only 15 cents per pound. As the lowest estimate for Type A FPC production is 25 cents per pound, on this basis it would appear unlikely that it could be competitive in any way with other protein concentrates. The market envisaged in North America for Type A FPC is as an ingredient of high protein snacks, pet foods and institutional diets. The ability of FPC to compete with other materials such as soya flour and skimmed milk powder on nutritional grounds alone and ignoring its lack of functional properties would appear very dubious, but the future commercial operating experience of Cardinal Proteins Ltd will no doubt prove whether or not it is marketable on a profitable basis. Also there may be further developments in the research currently in progress to evolve methods of improving the functional properties of FPC, which will enhance its marketability. Such additional processing will, however, increase the cost of production.

The Future of FPC

Although it would appear possible to produce a stable, bland, Type A FPC from non-fatty white fish, it has proved more difficult to produce a similar product from oily fish. The stability of Type A FPC permits storage and distribution but lack of functional properties makes it suitable only as a food additive. It can however, only be added in small quantities without adversely affecting the physical properties of the food to which it is added. The use of Type A FPC for the above purposes will depend on its ability to compete in price with other materials which could effect the desired nutritional improvement. Estimates of the likely production costs, which have been outlined above, suggest that it is unlikely that it could compete with other established protein concentrates, even in the most favourable circumstances eg Chile. Under these circumstances the question should be posed as to whether efforts towards the production of Type A FPC should be continued. As things stand at present the production of Type A FPC is in effect the production of a material of high nutritional value but of too limited a potential use and at too high a price. However, exact cost analyses will not be possible until large scale industrial production has been in operation for several years. Further development of Type A FPC production must depend upon technological progress, on the improvement of functional properties and the development of economic techniques for fish harvesting. For example the development of

cheaper extraction processes or the use of acceptable antioxidants, could change the picture considerably. Efforts to improve functional properties by treatment with hot alkali have already achieved some success experimentally but at present such processes would increase costs..

With regard to the US Government programme on Type A FPC, the argument has been advanced (MIT, 1970) that it should continue because the resulting information was a 'Public Good'. However the counter-argument could be advanced that money to be spent on the FPC programme might better be spent on something else. Certainly the prospects for FPC in the US domestic market are very poor, due to the lack of functional properties, the limited area of potential use, its high cost of production and the standards of the FDA. The potential for export to protein deficient developing countries also appears to be poor due to lack of price competitiveness with other protein food additives.

A cursory examination of the literature devoted to FPC reveals the imbalance between production research as opposed to marketing research. Despite considerable evidence that the strong flavour of fish meal is acceptable in many developing countries the view has hardened that a bland, colourless, high quality protein is required by the protein starved people of the world (Lovern, 1969). Although it is recognised that the greatest potential markets for FPC are in the developing countries much of the impetus for Type A FPC production has come from the developed countries. Because of this it seems that too much attention has been given to producing a product of the type required for marketing in developed countries, and too little attention given to suiting the market requirements of developing countries. This in turn has led to attempts to produce Type A FPC in countries where no ready market for this type of product exists and to ignore countries where dietary custom would suggest that an FPC with a pronounced fishy flavour would be readily accepted.

The prospects for the Type B and edible fish meal type product which can be produced at a very much lower cost than Type A FPC appear to be much better for those areas of the world where fishy flavoured materials of this type are not objectionable. In these areas the above products could be marketed as food in their own right thus avoiding the limitations of Type A FPC in this respect. The poorer storage life of these products compared to Type A FPC would be a disadvantage and need to be investigated. Possibly the future use of antioxidants may overcome this problem. It is of some significance that the many areas where the population are most likely to accept Type B FPC or edible fish meal are amongst those with the most pressing problem of protein malnutrition. As has been previously mentioned these include West Africa, Peru and parts of South-East Asia.

If Type B FPC or edible fish meal is to be produced in developing countries, it will be necessary to ensure that adequate raw material resources are available, as otherwise fish may be diverted from other traditional processing or from the fresh fish market. This would seem in the first instance to suggest the development of Type B and edible fish meal production in those countries that already have export orientated fish meal industries. The only developing country at present with scope for both production and domestic marketing on a large scale would appear to be Peru, but as new fishing resources are developed, West African and South-East Asian countries could perhaps develop industries producing fish meal and Type B FPC for both animal and human consumption. Both Peru and the various developed countries with fish meal industries eg Norway, Sweden and Iceland could also perhaps produce Type B FPC and edible fish meal for export to protein deficient developing countries. It has been suggested (Lovern, 1969) that future research to make greater use of potentially edible fish as human food, should be directed towards improving existing and the development of new methods of preservation rather than to the conversion into FPC. Since the fibrous texture of fish is a highly desirable characteristic, it would appear desirable to retain this as far as possible. This is especially true when considerable efforts are being made to simulate this texture in vegetable protein concentrates. Attention may also need to be directed towards upgrading of unacceptable fish species by modification of their flavour and texture (Jones, 1969).

FPC is only one of many fish products and it should be considered in the general context of fish product development. Pasteurised fish homogenates, fish protein hydrolysates and fish fermentation processes are all being developed as alternative sources of stable protein. At present there appears to be potential for the production of Type B FPC and edible fish meal on the lines mentioned above, but the priorities for work on these and other fish products in relation to the needs of developing countries need to be carefully assessed.

REFERENCES

Allen L E (1963) *Fishing News International* **2** No 1 (January-March)

Aylward F (1961) Interim Report to Government of Ghana on Foods and Nutrition, FAO Rome

Bakken K (1961) Paper read at FAO International Conference on Fish in Nutrition, Washington DC 19-27 September 1961

Blake J (1969) Paper read at Joint UNIDO/FAO Expert Group Meeting on FPC production, Rabat, Morocco 15-19 December 1969

Bureau of Commercial Fisheries (1966) Fishery Leaflet 584

Chichester C O and Monckeberg F (1969) Paper presented to Joint UNIDO/FAO Expert Group Meeting on FPC production, Rabat, Morocco 15-19 December 1969

Cordaro J B (1969) Paper presented to Joint UNIDO/FAO Expert Group Meeting on FPC production, Rabat, Morocco 15-19 December 1969

Dreosti G M and R P van de Merwe (1962) Fishing Industry Research Institute of South Africa, Progress Report No 64

Ershoff B H and Rucker P G (1969) *J Food Science* **34**, p 355

FAO (1958) *Proceedings of Nutrition Society* **17**, 153

FAO (1968) Amino Acids content of Foods and Biological Data on Proteins, Food Consumption and Planning Branch, FAO, Rome

FAO (1969a) *Yearbook of Fishing Statistics* **26**, (Catches and Landings)

FAO (1969b) Paper presented to Joint UNIDO/FAO Expert Group Meeting on FPC production, Rabat, Morocco 15-19 December 1969

FAO (1969)c) Paper presented to Joint UNIDO/FAO Expert Group Meeting on FPC production, Rabat, Morocco 15-19 December 1969

FAO (1969d) Prospects for world fishery development in 1975 and 1985 *FAO Fish Circ.* (118), 30 p

Finch R (1969) Commercial Fisheries Review, January 1969, p 25

Food and Drug Administration of USA (1967) *Federal Register* **32**, 2 February p 1173

Food and Drug Administration of USA (1969) *Federal Register* **34**, 24 December p 20, 224

Hallgren B and Sjoberg L (undated) Nabisco-Astra Nutrition Development Corporation

Hallgren B (1968) Paper read at Symposium on evaluation of novel protein products, Stockholm 9-11 September 1968

Hannesson G (1961) Paper read at FAO International Conference on Fish in Nutrition, Washington DC 19-27 September 1961

Harrison S (1964) *Andean Air Mail and Peruvian Times,* 13 November 1964

Holder C D, Kidd K H, Magyar WB, and Ross D S (1967) Paper at Conference on FPC, Ottowa 24 and 25 October 1967

Idler D R (1969) Paper presented to Joint UNIDO/FAO Expert Group Meeting on FPC production, Rabat, Morocco 15-19 December 1969

Jones N R (1969) Paper presented to Joint UNIDO/FAO Expert Group Meeting on FPC production, Rabat, Morocco 15-19 December 1969

Knobl G M (1967) *Food Technology* **21** (August) p 1108

Kracht U (1969) Paper presented to Ad Hoc Group on Amino Acid Fortification FAO/WHO/UNICEF, Protein Advisory Group, 7 and 8 May, Rome

Kwee W H, Sidwell V D, Wiley R C and Hammerle D A (1969) *Cereal Chemistry,* **46** (January) p 78

Lovern J A (1966) 'World Protein Resources', Advances in Chemistry Series No 57, American Chemical Society p 37

Lovern J A (1969) *Proceedings of Nutrition Society* **28** (1) p 81

Massachusetts Institute of Technology (1970) The Economics of Fish Protein Concentrate

Medwadowski B F, Van der Veen J and Olcott H S (1967) *J Food Science* **32** p 361-365

Medwadowski B F, Van der Veen J and Olcott H S (1968) JAOCS 45 No 10, p 709

Moorjani M N and Lahiry N H (1970) *Food Technology* **24** p 56

Munro I C and Morrison A B (1967) *Canadian Journal of Biochemistry* **45** 1779

Osterman S O (undated) Nabisco-Astra Nutrition Development Corporation

Pariser E R (1967) *Food Technology* **21** p 70

Roels O A (1969) Paper submitted to Joint UNIDO/FAO Expert Working Group Meeting on FPC production, Rabat, Morocco 15-19 December 1969

Sen D P, Sayanarayana Rao T S, Kadkol S B, Krishnaswamy M A, Venkata Rao S and Lahiry N L (1969) *Food Technology* **23,** 683

Sidwell V D (1967) Activities Report, **19**, Research and Development Associates Inc, Natick, Mass, p 118

Sidwell V D, Stillings B R and Knobl G M (1969) Paper submitted to Joint UNIDO/FAO Expert Working Group on FPC production, Rabat, Morocco 15-19 December 1969

Snyder D G (1967) *Food Technology* **21,** 1234

Snyder D G 'World Protein Resources' Advances in Chemistry Series No 57, American Chemical Society, p 49

Stillings B R (1967) Activities Report **19** Research and Development Associates Inc, Natick, Mass, p 109

Stillings B R, Hammerle O A and Snyder D G (1969) *J Nutrition* **97** (1) p 70

Swendsen D L (1967) *Chemical Engineering* 10 April p 176

Tannenbaum S R, Ahen M and Bates R P (1970) *Food Technology* **24** p 604

Tannenbaum S R, Bates R P and Bradfeld L (1970) *Food Technology* **24** p 607

Thomson F A and Merry E (1962) *British Journal of Nutrition* **16,** 175

Weinberg B (1967) *Fishing News International,* January p 16

Wick E L, Underriner E and Paneras E (1967) *J Food Science* **32** (4) p 365

Winsor M L (1969) Torry Advisory Note N39, Ministry of Technology, Torry Research Station, Aberdeen, Scotland

Yanez E, Borja I, Monckeberg F, Maccioni A and Donoso G (1967P *Food Technology,* **21,** p 1604

R 127584/1/659380 250 3/71 TP